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ABSTRACT

The changes which occurred in man's view of the solar system from the time of Ptolemy to that of Galileo are presented. Contained is a brief review of the chain of events which resulted in the acceptance of a heliocentric system. Ptolemy's theory is described and a diagram illustrates the paths of the epicycle of Mars according to his geocentric model. Challenges of the theory from prominent men such as Heraclides, Aristarchus, Copernicus, Brahe, Kepler, Tycho, and Galileo are discussed. A bibliography is included. (SA)

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A SYNOPTIC ANALYSIS OF THE CHANGE FROM THE GEOCENTRIC TO THE HELIOCENTRIC CONCEPTION OF THE SOLAR SYSTEM

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Curiosity as characteristic of Man is perhaps best exemplified by the progressive development of a world view. It was Ptolemy in the second century who observed that the motion of the sun around the earth was not perfect and circular. This seemed to him at first glance to defy the Aristotlian model. After a long and tedious mathematical analysis, Ptolemy introduced a model in which he could account for the apparent changes in the sun's path around the earth. He explained this by theorizing that the sun moves in a double circle.

According to the system, the sun was imagined to move in a large circle (deferent) around the earth and, at the same time, to revolve in a much smaller circle with its center on the larger circle. By adding the two circular motions of the sun together, the double circular motion produced the exact desired results. Thus, the small circle or epicycle of Ptolemy accounted for the nearness of the sun during winter months, as well as the observed facts that the sun apparently moves faster through the heavens during this period of time and relatively slower in its orbit during the summer months. This earth-centered system has come to be known as the geocentric system.

One of the fundamental problems that faced Ptolemy was to explain the motion of the planets. It was observed that Mars, Jupiter and Saturn occasionally traced out loops (retrograde motion) as they wandered through the sky. Retrograde motion is the apparent backward motion of a body through the

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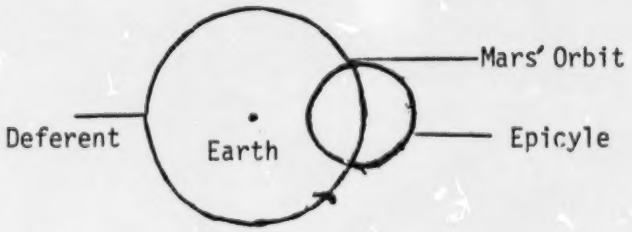
sky as it is seen from earth. On the other hand, the other two visible planets, Mercury and Venus, never showed retrograde motion and had the curious property that they never moved very far from the sun in the sky. During this time there was great preference for assigning purely circular motion to the celestial bodies since the circle was regarded as a pure or perfect geometric form.

Working within the current religious dogma, not putting the Gods in motion, Ptolemy interpreted the planetary travel in terms of an ingenuous system of circular motion on the earth. In his system the planets, stars, and moon followed circular paths about the earth. But superimposed on the paths were smaller circles (epicycles), each centered on a moving imaginary point located on the larger circle. However, many epicycles were needed in order to reproduce the observed position of the planets. A diagram of deferent and epicycle follows:



By postulating that the center of the Mercury and Venus epicycle always lay on the straight line that connect the center of the earth and the moving sun, Ptolemy accounted for the fact that these planets are always fairly close to the sun in the sky. He also proposed that the planets were powered by the four elements which are earth, water, air, and fire.

The Ptolemaic system became the established and official world view for many years. Some psychologists believe that a person must be at least mildly

egocentric to function effectively in society. Perhaps a similar need explains the fervor with which the geocentric universe of Ptolemy was adopted. His model also fitted the dominant religious dogma of the time which enhanced its popularity.

Even with the backing of the church, Ptolemy's geocentric model was the subject of controversy. It was a student of Plato, Heraclides of Pontus, who advocated a modification of the geocentric system. He is usually attributed with the assumption that Mercury and Venus, which always appear to be near the sun, do in fact revolve around the sun rather than the earth, while the remaining planets together with the sun and its system of two satellites revolve about the earth.

If Heraclides' ideas did not shake the proponents of the geocentric system, then Aristarchus' ideas of a new world system mildly shook its foundation in the third century. He proposed what was, according to him, a much simpler model. This model required all the bodies to move in circular orbits around the sun (heliocentric). This seemed quite reasonable to Aristarchus because it greatly simplified the apparent motion of all the bodies. If the heliocentric model were true, then the earth, like the other planets, must rotate in a circle with the sun at the center. At the end of a 6-month period, the earth must be on the far side of its orbit about the sun relative to its starting position.

If the same star is observed from the earth on the first of January and again on the first of July, then relative to a background of stars that are much further distant, the star in the foreground must appear to have shifted slightly. Such an apparent shift in the position of the near star was called stellar parallax. However, no stellar parallax was in fact found by the Greek. This is not surprising, however, considering that they had no sophisticated

method of observing the position of stars relative to one another. Such a stellar parallax does exist, but the angular difference in the apparent position in the near stars is so small that it would not have been observed by the Greek.

Some ideas of Aristarchus were revived by Copernicus several centuries later. His model proposed that the earth revolved about the sun, as did the planets, and that the daily rising and setting of the stars was correctly ascribed to the rotation of the earth on its axis. Although the Copernican solar system is usually remembered as a set of sun centered circular orbits, Copernicus in fact followed the practice of Ptolemy in including epicycles. However, the Copernican system was supposed to have mathematical harmony which was lacking in Ptolemy's work. But in fact, the Ptolemic system was successful in predicting the changing positions of both stars and planets. Its discrepancies were in planetary position and the precession of the equinoxes which did not conform with the best available observations. The precession problem was enhanced by the social pressure for calendar reform.

In addition to the Copernican book which he had published on his death bed, two astronomical events occurred that helped to cause the revolutionary transition. One of the events which put holes in the Ptolemaic system was the appearance of a supernova in 1572. The star is said to have been brighter in the sky than anything except the sun, the moon, and Venus. It was even visible sometimes during the daylight but it disappeared early in 1574. If it were a new star, it contradicted the old view that the sublime heavens neither change nor generate. People reminded themselves that God had ceased to work on the seventh day. Attempts were made to show that the star existed only in the sublunary region, but Galileo exposed the inaccurate observations

from data available to support this view. After all Copernicus had only put forward an alternative system of the skies which he claimed to be superior to the ancient one. Individuals were encountering inconvenient facts of which they could deny no longer.

In 1577 a new comet appeared, and even some people who disbelieved the Copernican System had to admit that it belonged to the upper sky and not the sublunary region. As it cut a path through the inpenetrable crystal sphree that formed the sky, it encouraged the view that spheres did not actually exist as part of the machinery of the heavens. The old supposition that comets were formed out of mere exhalations from the earth which ignite in the sphere of fire within the sublunary realm was contradicted. Quite apart from the attack which Copernican had made upon the system, the foundation of the Ptolemaic universe was beginning to shake. Consequently, people became conscious of the transitional stage in which astronomical science was moving.

Other significant accomplishments associated with the heliocentric system were made by Brahe, Kepler, and Galileo. Without the aid of the telescope, Tycho Brahe made precise measurement of the positions of Mars. Kepler showed that the motion of Mars, deduced from Tycho's observations, was not in good agreement with the Ptolemaic system because it disproved the idea of circular motion by planetary objects. Thus, Kepler's laws helped to reaffirm the Copernican belief that the sun was in the center of the solar system.

Galileo's discoveries of the phase of Venus, the moons of Jupiter, and sunspots were also strongly discordant with the Ptolemaic philosophy. And thus, these chains of events caused the change in the general acceptance of the reality of the heliocentric system compared to the geocentric system.

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